Award Number: W81XWH-06-1-0761

TITLE: Surgical Technology Integration with Tools for Cognitive Human Factors (STITCH)

PRINCIPAL INVESTIGATOR: W. Brent Seales

CONTRACTING ORGANIZATION: University of Kentucky Research Foundation
Lexington, Kentucky 40506-0057

REPORT DATE: October 2007

TYPE OF REPORT: Annual

PREPARED FOR: U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

1. REPORT DATE	2. REPORT TYPE	3. DATES COVERED
30-08-2007	Annual	24 JUL 2006 - 23 JUL 2007

4. TITLE AND SUBTITLE

Surgical Technology Integration with Tools for Cognitive Human Factors (STITCH)

5a. CONTRACT NUMBER

5b. GRANT NUMBER
W81XWH-06-1-0761

5c. PROGRAM ELEMENT NUMBER

6. AUTHOR(S)
W. Brent Seales

Email:

5d. PROJECT NUMBER

5e. TASK NUMBER

5f. WORK UNIT NUMBER

7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)

University of Kentucky Research Foundation
Lexington, Kentucky 40506-0057

8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING / MONITORING AGENCY NAME(S) AND ADDRESS(ES)
U.S. Army Medical Research and Materiel Command
Fort Detrick, Maryland 21702-5012

10. SPONSOR/MONITOR'S ACRONYM(S)

11. SPONSOR/MONITOR'S REPORT NUMBER(S)

12. DISTRIBUTION / AVAILABILITY STATEMENT
Approved for Public Release; Distribution Unlimited

13. SUPPLEMENTARY NOTES

14. ABSTRACT

Evaluation of surgical skill in MIS can be made more accurate, objective, and general by considering cognitive and environmental factors such as mental workload, stress, situation awareness, and level of comfort with complex tools. This research will show that a comprehensive framework for measuring cognitive human factors in MIS settings will provide an important, statistically significant set of (largely overlooked, in this domain) nonredundant metrics for evaluating performance in the context of new technologies, tasks, and learning methodologies.

15. SUBJECT TERMS
Cognitive factors, mental workload, MIS, plug-and-play

16. SECURITY CLASSIFICATION OF:			17. LIMITATION OF ABSTRACT	18. NUMBER OF PAGES	19a. NAME OF RESPONSIBLE PERSON
a. REPORT	b. ABSTRACT	c. THIS PAGE			USAMRMC
U	U	U	UU	17	19b. TELEPHONE NUMBER *(include area code)*

Table of Contents

Surgical Technology Integration with Tools for Cognitive Human Factors (STITCH)

2007 Annual Report

---

1. Introduction

The need for accurate assessment in surgical training has become even more important with the development of new surgical technologies, many of which have transformed methods of treatment for both the patient and the surgeon. Difficult-to-master technologies such as the components of Minimally Invasive Surgery (MIS) highlight the need for surgical competence but do not inherently provide a solution for how to define and measure it. The long term goal of this research is to build an integrated surgical technology environment designed for the continuous monitoring of task performance, with a particular focus on the inclusion of important but currently-overlooked cognitive measures.

Evaluation of surgical skill in MIS can be made more accurate, objective, and general by considering cognitive and environmental factors such as mental workload, stress, situation awareness, and level of comfort with complex tools. This research will show that a comprehensive framework for measuring cognitive human factors in MIS settings will provide an important, statistically significant set of (largely overlooked, in this domain) non-redundant metrics for evaluating performance in the context of new technologies, tasks, and learning methodologies.

Software development efforts will produce the general-purpose Plug-and-Play (PnP) framework and application-specific tools usable in that framework. Well-defined methodology will be incorporated in the development process to insure required safety, reliability and robustness attributes for the problem domain. The human studies used to adapt, select, and validate the cognitive measures will be divided into four parts: an *equivalence testing* phase followed by three *validity studies*. The equivalence study will ensure reliability of test results after minor modifications. The subsequent validity tests will assess *construct validity* (the extent to which our measures of stress and workload dissociate from measures of performance in situations where, theoretically, they should); *concurrent validity* (sensitivity to differences among surgical conditions known to differ substantially in difficulty); and *predictive power* (degree to which measures can predict more complicated indices of surgical proficiency, including adaptive aspects of performance on which students have not received explicit training).

The STITCH project will develop a specification, design, and implementation of an integrated surgical training and assessment framework and will provide assessment results for specific cognitive measures, including validity and predictive studies. These results will be useful for implementing improvements in training methods that seek to use valid cognitive measures as part of the assessment strategy.

2. Major Accomplishments

In this section we provide a functional view of major tasks accomplished during the 2007 project year. These include (1) timeline in obtaining human subject approval, on which the cognitive

experiments depend; (2) progress in the design of the technical architecture, including the PnP; (3) cognitive human factors; and (4) the production of research media.

2.1 Human Subject Approval

This project began on September 26, 2006 and involves human subjects for which we are requesting institutional IRB approval. This approval was granted by the University of Kentucky IRB on January 9, 2007. The protocol, proposal and IRB approval were then forwarded to ORP for final approval. On 7/25/07 we received ORP approval and on 9/4/07 the University of Kentucky's IRB approved modifications and provided finalized consent forms for enrolling participants. More detail on the subjects and our study is provided below.

Clinical Collaboration
We have met once per week at the Center for Minimally Invasive Surgery in the Medical School at the University of Kentucky in order to establish and supervise the research plan for developing technology and an experimental plan related to urological surgical training and intervention. The Co-PIs (Seales, Carswell, Strup) have used these meetings for planning and for specific events such as:

- Direct staff to set up experimental stations and to develop videotaped, narrated information for skills performance studies and to support subsequent studies
- Use MIS conference room to UK OR telesurgery link so that Dr. Seales and Dr. Carswell could observe two live remote prostatectomy procedures performed by Dr. Strup in OR 9 of the UK hospital. This telesurgery session included two way audio and video links so that pertinent questions that Dr. Seales and Dr. Carswell had could be answered by Dr. Strup in real time while he conducted the procedure. Two cases were observed: one with a robot (DaVinci) and one as straight laparoscopy.
- Prepared DVD and reviewed copies of earlier recorded Narrated Teaching Case (Prostatectomy) which featured interaction between Dr. Strup in the OR and Dr. Seales and Dr. Carswell in the MIS conference room. Copies were technicians so that they might view them on their own time and better understand the ideas and concepts that would allow advanced imaging techniques to increase the efficiency of selected surgical procedures.

2.2 System Tools and Architecture

PnP Framework *Display* System. The flexible, self-calibrating display framework as developed by the REVEAL project (and deployed and working at UMMC) is a single, monolithic display system that serves a single application. In moving forward into the integrated, multi-tasked PnP environment, we need to generalize the framework to allow multiple applications to render their output onto the tiled display simultaneously. This presents a number of challenges in terms of capturing the output and control information from multiple applications, to the display of these applications output on a shared display. We are researching off-the-shelf software solutions that we promise to allow us to integrate multiple OpenGL streams with existing window management software with minimal additional implementation effort. The goal is to implement a seamless OpenGL-based compositing window manager

extension, which preserves the flexible tiled display characteristic of the existing system but extends the system to allow the alignment of multiple projectors sharing a single desktop for high-resolution, collaborative displays. One member of the STITCH development team spent time getting training in the use of LynxOS-178, an FAA-certified commercial real-time operating system. LynxOS is being evaluated for the implementation of a high-reliability STITCH framework.

The Stereo-Endoscopy publication ("Evaluation of Stereo-Endoscopy for Image Field Reconstruction in Minimally Invasive Surgery") is drafted and ready for publication after a second round of data collection using the daVinci Surgical System at UK Medical Center. The additional data will allow us to quantify the error bounds of the reconstructed 3D points, giving an accurate depth range for which anatomical measurements can be trusted. The tiled display system developed under Project REVEAL has been expanded and enhanced greatly in the past year. Slow, expensive cluster-based rendering has been replaced with a much simpler and faster single server implementation using modern COTS hardware. The number of tiled projectors in our display was expanded from eight to twelve, bringing total available pixel resolution to more than three times that of the highest resolution HD projectors. The display system can now handle both standard definition and high definition video streams, from both live inputs and from disk. It functions in standard two-dimensional mode as well as three-dimensional output using polarized lenses. Output capabilities will be expanded in 2008 to allow a full windowed environment for the visualization of multiple simultaneous inputs in a high-resolution tiled, projected display. The same upgrades were rolled out to our mirror site at the University of Maryland Medical Center's MASTRI Center.

We have modified the video client (a.k.a. the "SmartImage" video client system) in order to prepare it for integration with the emerging PnP architecture. It has been overhauled to handle multiple simultaneous data streams (multiple client connections, but only one is displayed at a time). In terms of computational efficiency, the SmartImage client used only a small portion of a large and relatively slow geometry library (CGAL) to determine how to place images on the display. The library was very functional for a first prototype but included cumbersome overhead that made configuration and performance issues a concern for our leaner production version. We replaced that library with a much smaller and faster library (GPC) that contained little more than the functionality smartImage required. This reduced the size of the SmartImage code base and deployed executable image, made SmartImage compile five times faster, and the new library seamlessly integrates into the SmartImage architecture. Additionally, a calibration speed improvement should be noticed on larger displays because the new library requires far fewer function calls and implements several functions through C macros rather than C++ class methods.

Using this software we have the capability to play captured video and to display video from a DVD (2D and 3D). The performance is measured at 30fps @110ms latency video (including stereo video). We have worked to integrate HD results from the REVEAL project in order to integrate within the PnP framework, including HD capture capabilities with AJA card, integrated with the Stryker 1088 HD scope.

Endoscopic Tools Highlights. Our video capabilities were greatly enhanced with the integration of a Stryker 1088 HD endoscope into our display system. We can capture and display full frame-rate 1280x1024 video. Overall display latency is around 200 milliseconds, near the upper bound of the acceptable limit for interactivity.

We completed calibration of two stereoscopic endoscopes for the assessment of taking intra-operative metric measurements. Thanks to collaboration with Dr. Stephen Strup of the University of Kentucky Department of Surgery, we gained access to the daVinci Surgical System, a robotic surgical platform, to capture calibration data for its stereo scope. We compared those results to that of an older Vista StereoScope in our lab. Our previous results with the Vista had been nearly unusable, but the daVinci robot showed a four-fold improvement in measurement accuracy. This illustrates that calibration of high-distortion endoscopes with a pin-hole camera model is clearly possible, and useful data may come of this later. Given the proper constraints, intra-operative measurement may be possible and warrants future study.

Inertial endoscopic tracking. We are evaluating the use of an inertial measurement unit (IMU) to track the endoscope for improved image reconstruction. We purchased a MicroStrain Inertia-Link for this purpose and are using software developed by Fremont Associates to integrate it with our system. A prototype system should be ready in 1-2 months. We hope that this will be the first of many instruments to fully integrate with the STITCH software platform currently being implemented.

Faro reconstruction. We have collaborated with the SmartImage project to develop a method for accurate 3D reconstruction using through-the-scope video. The FaroArm, a coordinate-measuring machine with laser scanner, can scan objects in 3D to produce ground truth data for image registration. It can also be attached to an endoscope to provide extremely accurate tracking for the best possible structure-from-motion computer vision techniques.

PnP Framework Requirements

We have installed and begun using the Telelogic DOORS (Dynamic Object Oriented Requirements System) requirements management system to manage project requirements. The software was received and installed, and staff has completed training on the deployment and use of the system.

With our tools framework in place, we have begun identifying and documenting end-user and system requirements for the PnP Framework system. The requirements identified to date have included (1) fundamental goals for the system—*i.e.*, its intended audience and use; (2) basic architectural components of the system including input stream types, outline of a passive information repository, and output stream and display requirements; and (3) basic scenarios for the use of the system in clinical research settings.

Framework Input Modules

Sensors to augment traditional image streams are one of the critical input stream components for the PnP framework. Our first sensor implementation will be based on a temperature-compensated six degree-of-freedom inertial measurement unit (IMU). We acquired equipment and have begun testing, to include the creation of software infrastructure to communicate with the device from within the STITCH framework.

The formalization of an initial user requirements document was completed, based on requirements embodied in the initial STITCH project proposal. These requirements describe, from the user's point of view, required and desirable attributes of the system to be engineered.

PnP framework input modules will initially encompass (1) NTSC video, (2) synchronized HD audio/video, and (3) high-resolution location information derived from a six degree-of-freedom inertial measurement unit (IMU). Video input modules will be derived from the VIBE system of project REVEAL. The IMU input module is new development being carried out under the STITCH project.

During the year significant progress was made on the design, implementation and test of the IMU input module. The current design supports two modes of operation—a synchronous procedure-call mechanism that will return one measurement for each call, and an asynchronous callback mechanism that will be driven by the IMU device's maximum sampling rate. The design being implemented to support these two modes of operation is shown in Figure 1.

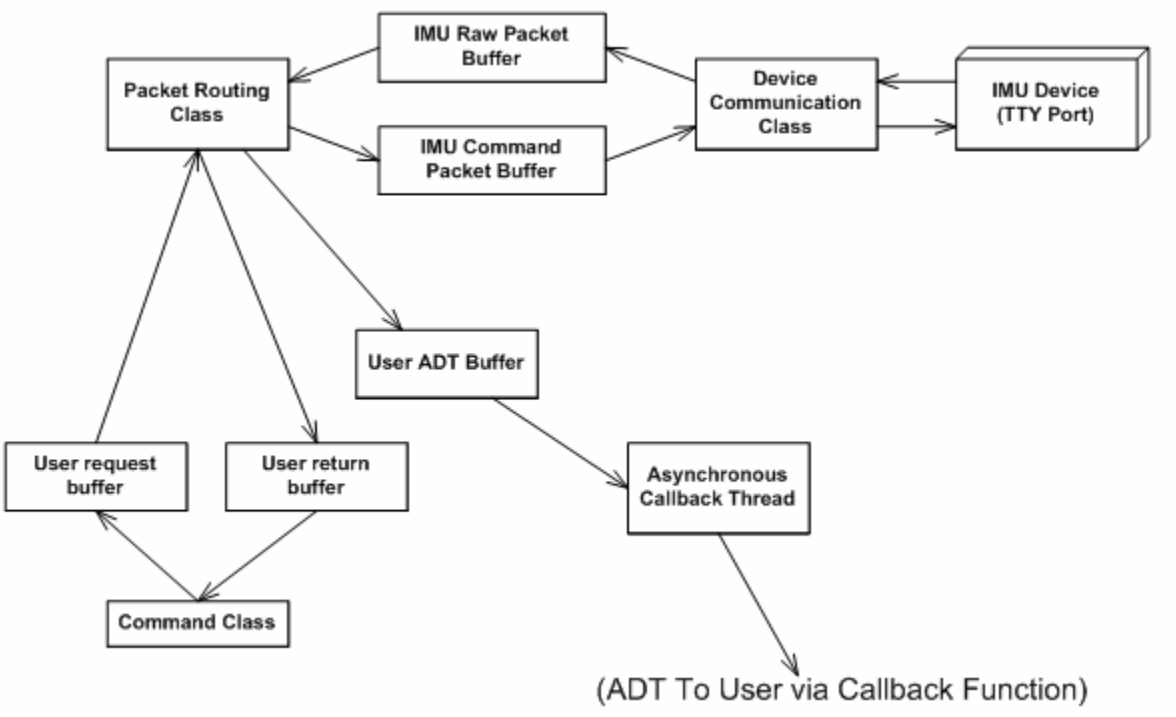

Figure 1: IMU API System Architecture

We have implemented the synchronous procedure-call mechanism, which includes the completion of all design, coding, verification and validation activities. Testing demonstrated that the implemented API functionality correctly provided single-precision linear acceleration and angular rate data to calling programs using the matrix abstract data type of the BOOST template library.

IMU API: The design, implementation and system-level test of the IMU API was completed during the quarter, and the software was deployed for use by UK CVVM staff of STITCH. The

completion of the API library will support implementation of the first PnP framework input device based on inertial tracking of a COTS laparoscope. The IMU API deliverable was transferred from Fremont Associates and their technical staff helped the STITCH team at UK begin integration with STITCH framework. We are currently developing 3D tracking software using inertial measurement to improve endoscopic reconstruction techniques. Preliminary studies of this approach were prepared for the imminent Q4 2007 (October 2007) site visit from TATRC personnel.

Phase I Protocol Support Technology and Collection Framework: STITCH development team members are working with Dr. Carswell's team to automate much of the data collection currently required by the cognitive task studies. At present, task complexity measures and subject time estimations are recorded manually, by a research assistant observing the performance of the task. During the year we have been researching and testing software/hardware solutions that will allow this data to be captured by software, directly from the subject's verbal utterances. Based on this work we have begun implementation of *speech recognition* capabilities to improve automation and decrease workload of human factors studies. This will allow for more subjects to be processed with less data entry and quicker analysis.

Tools for Prostatectomy

In order to test a new visualization and navigation tool for use in prostatectomy cases that present ambiguous geometries and difficult approach angles we have developed software for accurate feature-based texture mapping onto 3D geometry. The first test of the algorithms on which this software is based uses a FaroArm 3D laser-based scanner to capture geometry and a high resolution digital camera to capture 2D images. The 3D texture registration problem is the correct application of texture coordinates to a captured 3D mesh. The goal in the case of the surgical procedure is to orient the high resolution scope view with respect to anatomical fiducials, pre-opertative CT scans, and known angles established at the start of the surgical procedure. Registration can aid in orientation and identification of crucial anatomical structure. In our current implementation we work with data that is a combination of untextured 3D point sets from a Faro Laser ScanArm and high-resolution texture images. In order to place the texture onto the 3D mesh, we perform a calibration procedure which gives us the intrinsic (i.e. focal length and lens distortion) and extrinsic (relationship between 2D pixel coordinates in the camera and 3D coordinates in the ScanArm) properties of the camera. These properties allow us to perform a projective transform to map the texture onto the mesh.

One of the problems we are working on is using a calibrated texture and model pair to map uncalibrated textures onto the same model. In the data we are working with, the uncalibrated image is assumed to be of the same object. However, the object may be deformed differently from the captured model (i.e. non-rigidly deformed during the surgery). We have implemented an algorithm which uses template matching to compute reliable point correspondences between the images, then performs a simple rotation and translation based on these correspondences. If the model had only undergone rotation and translation with respect to the camera, this would be sufficient, but we must also deal with non-uniform distortion due to the object's possible deformation. This is done by first finding strong feature points (as determined by minimum gradient eigenvalues) in the calibrated image, then finding their corresponding points in the uncalibrated image using an optical flow algorithm. The points are inserted into a Delaunay

triangulation, and then a triangulation warp is applied to the uncalibrated image in order to place the features in to the same positions as the calibrated image. Using this method it is possible to use a calibrated image to map uncalibrated images with desirable features (i.e. enhanced resolution, improved lighting) onto the previously acquired 3D mesh. Initial testing of this algorithm has yielded good results which are currently being used as a benchmark for a testing review. We are working on making the algorithm to be scale-independent (in the current algorithm, the model may be deformed but it is assumed to be approximately the same distance from the camera).

In terms of the visual presentation of this process and its computational requirements, we have started an analysis as a function of desired image resolution and available computational cycles. Due to the high resolution of the textures used (39 megapixels), special techniques must be employed in order to display the textured model using standard graphics hardware. Currently the texture is split into multiple textures with an overlapping border, such that each polygon is fully contained by at least one split texture. Optimizations for this splitting and rendering process are underway so that it requires less texture memory and renders faster, as well as allowing for optimal display of the texture on machines which cannot fit the entire texture into memory.

2.3 Cognitive Human Factors

Our activities during Year 1 were targeted at fundamental psychometric issues (e.g., reliability and validity studies) necessary for the development of a cognitive human factors toolkit for laparoscopy. The overall aim is to develop a toolkit that will be integrated into our surgical technology framework for use in assessing surgical training methods, new surgical technologies, and even surgical expertise. The activities of Year 1 included facility and instrumentation development, research protocol development, and actual data collection.

Facility/Instrumentation Development. Our laboratory space and resources were enlarged during the current research cycle in order to allow us to collect new types of behavioral data (eye-tracking) and to increase our ability to complete participant-running and multiple user studies in parallel. The improvements include the following:

- **Completion of a secondary CVVE usability lab**. In order to free up the main surgical simulation system at the CVVE for software development and testing, a second laboratory was equipped to support participant-running using a training stand and equipment similar to those used in the MIS Center on the UK Medical Center. The new lab includes a Stryker 888 laparoscope, surgical trainer, and Maryland dissectors, Sony 19- inch monitor, Stryker Quantum 3000 light source, and Stryker 888 video camera.

- **Completion of main campus usability lab**. This lab contains equipment equivalent to that in the CVVE and MIS facilities, and it is housed in the UK Psychology Department's research annex on the UK main campus. This lab allows us to more easily recruit research participants from the PSY 100 subject pool who sometimes have difficulty traveling downtown to participate in research at the CVVE.

Figure 2: The Usability lab at the Center for Visualization

Figure 3. Stereo-Head and digital cameras with Classic lenses attached.

- **Delivery of FaceLAB**. We received our FaceLAB 4.1 eye-tracking system during the last quarter of 2007. Since that time, we have worked on the setup of the system in the main CVVE lab, and we have collected pilot data to demonstrate the use of the system. The following images shows the arrangement of the device when used by a UK surgeon in the lab context, as well as a screen shot of the user interface showing a variety of real-time blink measures, saccade measures, and position tracking.

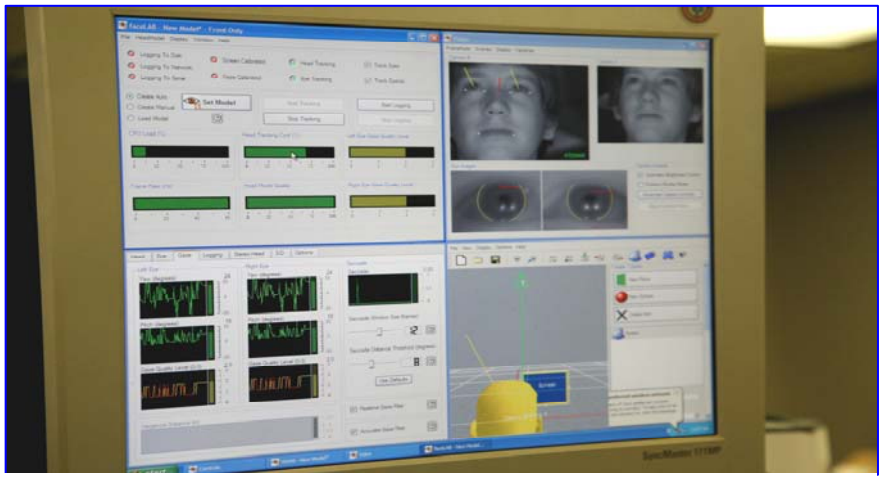

Figure 4. Four displayed windows of the FaceLAB: The Main Window, the Control Window, the Video Window, and the World Model Window (clockwise).

- **Eye tracker training**. Core members of the research team, including Melody Carswell, Matt Field, Cindy Lio, and Qiong Han, completed two days of training with a FaceLAB engineer who visited our main CVVE lab on December 3rd and 4th. The training allowed us to find ways to record a wider variety of participants (e.g., those with and without glasses, with different iris/pupil contrast levels, etc.). It also allowed us to acquire information necessary for the successful integration of FaceLAB and STITCH software.

Protocol Development

- **IRB/HSRO approval.** The following is a timeline describing our progress in developing and testing the subjective measures for the toolkit:

  al human subjects review completed, and approval given, by UK IRB.

  2/07 – UK approval and protocol materials sent to Army ORP

  4/07 – Initial review by contact officer.

  5/07 – Updated PI training completed and full administrative review by ORP initiatied.

  6/07 – Full review feedback received.

  7/18/07 – Response and modification of protocol by PIs.

  7/24/07 – Approval granted by ORP, pending approval of required modifications by UK IRB.

  9/4/07 – UK IRB approves modifications and provides finalized consent forms for enrolling participants.

  9/4/07 – 9/7/07 -- over 1400 PSY 100 participants were screened for suitability for enrollment in our studies in a series of large-scale screening sessions. Our inclusion criteria give preference to students who are preparing for employment in health-care fields *and* who report playing video games on a regular basis.

  9/21/07 – Changes completed at the Usability Lab at the CVVE to allow participant-running in an area apart from main STITCH programming/development.

  9/24/07 – 9/28/07 – 3 pilot subjects run to estimate number of trials per participant that can be completed within allotted time.

  10/10/07 – 14 enrolled and run through full protocol.

- **Continuation review in process.** The IRB continuation review materials were submitted on November 26, 2007 and will be reviewed during the week of December 17, 2007. Modifications that were made included:

  (a) Personnel list. Four Psychology undergraduate students who will be conducting the study as their partial fulfillment of an independent research course, and the Information Technology Manager at MIS were included in the continuation review personnel list.

(b) Address change. Since our offices and labs are at the Center for Visualization and Virtual Environments, we requested to receive future IRB notifications at 1 Quality Street, Suite 800, Lexington, KY 40507-1464.

- **Training procedure**. The 8-minute training involved showing to the participants the three tasks. We explained the operation of the dissectors, the setting, and the three tasks in the beginning of the session. The participants then practice each of the tasks in open view.

- **Task Development.** The following three tasks were used as experimental tasks in an effort to be consistent with training tasks currently in use at the UK MIS Training Center. The goal of the *pegboard task* for the participant is to transfer as many rings as possible from a small dish and place them on a pegboard (left) They are to transfer as many as they can per unit time (90 seconds for this study). For the *cobra rope task*, the goal is to "inspect" the rope by transferring it with two graspers down its entire length as quickly as possible while only touching sections of rope that are a specific color (center). For the *cannulation task*, the goal is to thread a pipe cleaner through a plastic tube as quickly as possible without bending the pipe cleaner (right).

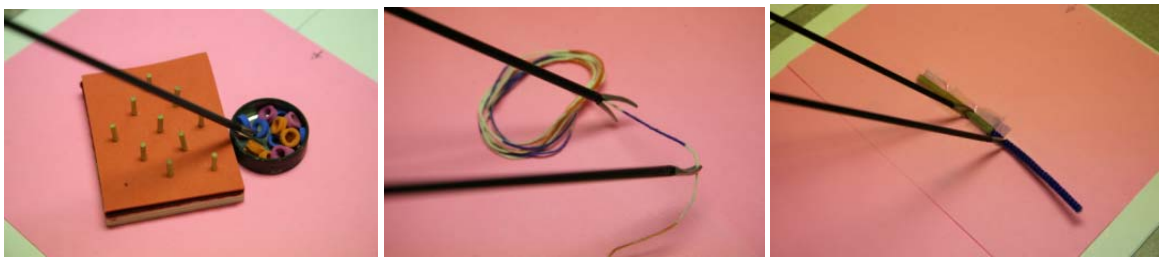

Figure 5: As seen through the laparoscope, from left to right: Pegboard task, cobra rope task, and cannulation task.

- **Modification of Questionnaires.** We modified the verbal questionnaires after conducting the study with three Psychology students. The digitized questionnaires that we developed previously took significantly longer to complete than the written version. Consequently, for the verbal protocol, we explained to the participants the questionnaires and scoring system (zero to 100) at the end of first trial. In the remaining trials, we read the NASA-TLX, NASA-TLX paired comparisons, and MRQ questionnaires to the participants without description. We also read the SSSQ to the participants at the end of each trial of the last block.

Data Collection

- **Reliability Study.** We collected data at both Breckinridge on campus and at the Center for Visualization and Virtual Environments (CVVE). A total of sixty-eight PSY 100 students participated in the study, of which 21 of took place at the CVVE and 48 at Breckinridge. Written and verbal conditions were assigned by an odd and even numbers

system across participants while tasks were randomized within each block (a total of 5 blocks). After completing each task, the participants answered the questionnaires according to their assigned protocol (visual/written vs. auditory/vocal versions).

- More than half of the data have been coded and entered into our database and very preliminary analyses have been completed. We are finding that only some subscales of the NASA-TLX have adequate reliability (e.g., "mental demand" but not "temporal demand"); however, these reliability estimates have not yet been corrected for experimenter effects (i.e., slight differences in the way different experimenters might have administered the materials). A more extensive analysis will be completed when the remaining data are entered, at which point we can also ask questions about relative correlations of each administration method and data from performance measures (both primary task and secondary task performance).

2.4 Production of Research Media

This year we have systematically captured detailed research footage, including methods, systems, and interviews, in order to produce a findings documentary that will detail methods, approaches, systems, and findings. This is currently in production and we expect to complete the project in two phases, the first finished in mid-2008 and the second at project year 2 completion.

3. Project Milestones 2007

The 2007 project plan led us to near completion of visualization and display technology development, moving the technical component of the project toward a support role for remaining ergonomic assessment activities at the University of Maryland medical center. We have been granted a no-cost extension to complete the ergonomic assessment, with the technical team providing support for the equipment as the protocol is executed. The accomplished milestones and our progress in reaching each for the year are assessed in the sections that follow.

Project Milestones

This study was designed for one year, although we have made progress and expect to use second year funds for continued development and experimentation. We will work to complete technical milestones in each of the following areas:

1) *Design and Build First Generation PnP Framework*
   - *a)* Identify and document requirements from various constituencies including clinical, training, evaluation, peripheral devices, MD PnP. (Months 1-4).
   - *b)* Define and document functional and structural architecture for framework. Define data architecture in terms of XML data streams and SQL database structures. (Months 3-6).
   - *c)* Input Modules (Sensors, positioners, *etc.*)
     - *i)* Design, documentation and review. (Month 7)
     - *ii)* Implementation and unit test. (Months 7-9).
   - *d)* Processing Modules (API and implementation for "toolkit" of processing methods.)
     - *i)* Design, documentation and review. (Month 9).
     - *ii)* Implementation and unit test. (Months 9-11).

e) Output Modules (Displays, effectors, *etc*.)
  i) Design, documentation and review. (Month 8).
  ii) Implementation and unit test. (Months 8-10).
f) Archive and Query Modules (Underlying database and query engine.)
  i) Design, documentation and review. (Month 7).
  ii) Implementation and unit test. (Months 7-9).
g) Integration and Testing. (Month 11-12).
h) Deployment. (Month 12).

2) *Design, Implement, and Test Advanced Surgical Tools*
   a) Design technical framework for potential solutions (simulation/lab tests – Months 1-4)
   b) Consult during design phase with UMMC experts (Months 1-3)
   c) Deploy for testing by experts at UMMC (Months 5-12)
   d) Revise implementations as required (Months 6-12)
   e) Prepare for testing in cognitive frameworks (Months 10-12)

3) *Design Cog Monitoring Protocols*
   a) Complete the adaptation of secondary task (time estimation) and subjective workload measures to make them appropriate for the surgical context and to allow for integration of administration and analysis functions into the proposed continuous performance monitoring system. (Months 3 to 5.)
   b) Provide preliminary evaluation of the use of eye blink and pupil size measures of mental workload in a training context with possible integration of these measures into the continuous performance monitoring system. (Months 3 to 5.)

4) *Design and Execute Human Study*
   a) Complete human subjects approval and initiate subject recruitment. (Months 1 and 2.)
   b) Execute human studies of construct, concurrent, and predictive validity within the lab and training environment. (Months 6 to 12.)
   c) Conduct user evaluation of use of surgical robot (*vs*. conventional procedures), with and without on-demand tools, using our new suite of cognitive metrics. (Months 13 to 24.)

Project Conclusions and Deliverables

The project has received Year 2 funding and will extend reported results. Final conclusions will be reported in the final report at the end of Year 2. We have made available all source code detailed for the technical environments and algorithms above, including technical specifications for hardware and configuration information where necessary. In addition, we have published papers and made presentations as detailed in the reference list. One pre-publication paper is included in the appendix for reference.

Appendix A: Project Personnel

Name	**Role**	**Location**	**2006 FTE**
W. Brent Seales, PhD	Principal Investigator	UK Center for Visualization	30%
Stephen Strup, MD	Co-Principal Investigator	UM School of Medicine	10%
Steve Bailey	Media Specialist	UK Center for Visualization	100%
Kim Hall	Administrative Support (Budget, Reporting)	UK Center for Visualization	20%
C. Melody Carswell	Senior Researcher	UK Department of Psychology	25%
Duncan Clarke, PhD	Technical Project Lead	Fremont Associates, LLC	50%
Ryan Davis	Student Programmer	UK Center for Visualization	25%
Matt Field	Program Systems Analyst	UK Center for Visualization	100%
George Landon	Research Assistant	UK Center for Visualization	50%
Cindy Lio, PhD	PostDoctoral Researcher	UK C enter for Visualization	50%
James Hoskins	Human Subject manager	UK School of Medicine	20%

Appendix B: Publications

1. Carswell, C.M., Lio, C., Seales, W.B. and Clarke, D. (in submission). Situation awareness during the performance of laparoscopic training tasks. Proceedings of the Human Factors and Ergonomics Society.
2. Carswell, C.M., Clarke, D., Lio, C., Kurs, Y., and Seales, B. (2007). Measuring subjective stress profiles during surgical skills training. MMVR, Feb. 2007, Long Beach, CA.
3. Lio, C. Carswell, C.M., Bailey, K., Clarke, D., Seales, B., and Payton, M. (2006). Time estimation as a measure of mental workload during the training of laparoscopic skill. *Proceedings of the 50th Annual Meeting of the Human Factors and Ergonomics Society*, Santa Monica, CA: The Human Factors and Ergonomics Society.
4. C. Andy Martin, Duncan Clarke, C. Melody Carswell, Adrian Park, and W. Brent Seales. Analysis of Immersive Display Architecture for Laparoscopy, in preparation, submitted to IEEE Trans. On Information Technology in Biomedicine.
5. W. Brent Seales, Duncan Clarke, George Landon, Matthew Field, and Adrian Park, MD. Evaluation of Stereo-Endoscopy as a 3-D Measurement Tool, in preparation, submitted to IEEE Trans on Medical Imaging.